Evaluation and Comparison of the IRS-P6 AWiFS and the Landsat Sensors

NASA LCLUC Science Team Meeting
April 20 – 22, 2010

Gyanesh Chander, SGT at USGS EROS
Dennis L. Helder, SDSU
Gregory L. Stensaas, USGS EROS
Thomas R. Loveland, USGS EROS
Brian L. Markham, NASA GSFC
James R. Irons, NASA GSFC

U.S. Department of the Interior
U.S. Geological Survey
Landsat Data Gap!

- The EO community is facing a probable gap in Landsat data continuity before LDCM data arrive in Dec 2012

- A data gap will interrupt a 38+ yr time series of land observations

- Landsat data are used extensively by a broad & diverse users
  - Landsat 5 limited lifetime/coverage
  - Degraded Landsat 7 operations
  - Either or both satellites could fail at any time: both beyond design life

- Urgently need strategy to reduce the impact of a Landsat data gap
  - Landsat Program Management must determine utility of alternate data sources to lessen the impact of the gap & feasibility of acquiring data from those sources in the event of a gap
Primary Objectives

● Cross-calibration
  - Worldwide Test Site Catalog
  - Coincident Imaging Tool
  - Cross-calibration Results
  - Long Term Stability Monitoring

● Sensitivity Studies
  - Geometric Registration
  - Spectral Profiles
  - Spatial Resolution
  - Radiometric Resolution
  - BRDF & Atmospheric Effects (SSC)

● Application Evaluation
  - Multi-Resolution Land Characteristics Consortium (MRLC)
  - Monitoring Trends in Burn Severity (MTBS)
  - LANDFIRE
AWiFS Sensor Overview

AWiFS VITAL FACTS:

- Instrument: Pushbroom
- Bands (4): 0.52-0.59, 0.62-0.68, 0.77-0.86, 1.55-1.70 µm
- Spatial Resolution: 56 m (near nadir), 70 m (near edge)
- Radiometric Resolution: 10 bit
- Swath: 740 km
- Repeat Time: 5 days
- Design Life: 5 years

<table>
<thead>
<tr>
<th>Platform</th>
<th>Landsat 5</th>
<th>Landsat 7</th>
<th>Terra</th>
<th>IRS-P6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor</td>
<td>TM</td>
<td>ETM+</td>
<td>MODIS</td>
<td>AWiFS</td>
</tr>
<tr>
<td>Number of bands</td>
<td>7</td>
<td>8</td>
<td>36</td>
<td>4</td>
</tr>
<tr>
<td>Spatial resolution</td>
<td>30 m, 120 m</td>
<td>15 m, 30 m, 60 m</td>
<td>250 m, 500 m, 1 km</td>
<td>56 m (nadir), 70 m (edge)</td>
</tr>
<tr>
<td>Swath</td>
<td>183 km</td>
<td>183 km</td>
<td>2330 km</td>
<td>740 km</td>
</tr>
<tr>
<td>Spectral coverage</td>
<td>0.4~12.5 µm</td>
<td>0.4~12.5 µm</td>
<td>0.4~14 µm</td>
<td>0.52~1.7 µm</td>
</tr>
<tr>
<td>Pixel quantization</td>
<td>8 bit</td>
<td>8 bit</td>
<td>12 bit</td>
<td>10 bit</td>
</tr>
<tr>
<td>Launch date</td>
<td>1-Mar-84</td>
<td>15-Apr-99</td>
<td>18-Dec-99</td>
<td>17-Oct-03</td>
</tr>
<tr>
<td>Orbit type</td>
<td>Sun synchronous</td>
<td>Sun synchronous</td>
<td>Sun synchronous</td>
<td>Sun synchronous</td>
</tr>
<tr>
<td>Equatorial Crossing Time</td>
<td>10:00 AM</td>
<td>10:00 AM</td>
<td>10:30 AM</td>
<td>10:30 AM</td>
</tr>
<tr>
<td>Altitude</td>
<td>705 km</td>
<td>705 km</td>
<td>705 km</td>
<td>817 km</td>
</tr>
</tbody>
</table>
Relative Spectral Response (RSR)

L7 ETM+ RSR (Bands 1, 2, 3, 4, PAN)

Terra MODIS RSR (Bands 3, 4, 1, 2)

IRS-P6 AWiFS RSR (Bands 2, 3, 4)

CBERS 2B CCD RSR (Bands 1, 2, 3, 4)

L7 ETM+ RSR (Bands 5, 7)

Terra MODIS RSR (Bands 6, 7)

IRS-P6 AWiFS RSR (Bands 5)
Cross-Calibration Methodology

- Co-incident image pairs from the two sensors were compared

- The cross-cal was performed using image statistics from large common areas observed by the two sensors
  - Define Regions of Interest over identical homogenous regions
    - All ROIs have about 400 x 400 Landsat pixels (160000 points) and 214 x 214 AWiFS pixels (45796 points)
    - Bright and dark regions were selected to obtain a maximum coverage over each sensor’s dynamic range
    - All the saturated pixels and SLC-off pixels were discarded
  - Calculated the mean and standard deviation of the ROIs
  - Converted the satellite DN to TOA reflectance

- Performed a linear fit between the satellites to calculate the cross-cal gain and bias
Conversion to at-sensor spectral radiance \( Q_{\text{cal}} \)-to- \( L_\lambda \) & reflectance

- **IRS-P6 AWiFS sensor**
  - \( Q_{\text{cal max}} \) is 1023 for 10-bit AWiFS
  - \( Q_{\text{cal max}} \) is 255 for 8-bit AWiFS products (USDA)

- **AWiFS-B camera (B&D quadrant scenes):**
  - Minimum / maximum radiance for band 2 [\( \text{mw/cm}^2/\text{str}/\text{um} \)] ... 0.00000 52.34000
  - Minimum / maximum radiance for band 3 [\( \text{mw/cm}^2/\text{str}/\text{um} \)] ... 0.00000 40.75000
  - Minimum / maximum radiance for band 4 [\( \text{mw/cm}^2/\text{str}/\text{um} \)] ... 0.00000 28.42500
  - Minimum / maximum radiance for band 5 [\( \text{mw/cm}^2/\text{str}/\text{um} \)] ... 0.00000 4.64500
  - Same numbers for AWiFS-A camera (A&C quadrant scenes)

\[
L_\lambda = \left( \frac{L_{\text{MAX}}_\lambda - L_{\text{MIN}}_\lambda}{Q_{\text{cal max}} - Q_{\text{cal min}}} \right) (Q_{\text{cal}} - Q_{\text{cal min}}) + L_{\text{MIN}}_\lambda
\]

\[
Q_{\text{cal}<8>} = Q_{\text{cal}<10>}(\frac{255}{1023})
\]

\[
\rho_\lambda = \frac{\pi \cdot L_\lambda \cdot d^2}{ESUN_\lambda \cdot \cos \theta}
\]
L5 TM, L7 ETM+ & P6 AWiFS Image Pairs
L5 TM and AWiFS-BD Quads (ROI)
L7 ETM+ and AWiFS-BD Quads (ROI)
Reflectance comparison of ~500 polygons

TM Band2 TOA Reflectance

TM Band3 TOA Reflectance

TM Band4 TOA Reflectance

TM Band5 TOA Reflectance
L5 TM and AWiFS-AC Quads (ROI)
Long-term TOA Reflectance Trending (Sonoran & Railroad Valley Test Sites)

<table>
<thead>
<tr>
<th>AWiFS</th>
<th>Band</th>
<th>Slope</th>
<th>t-value</th>
<th>p value</th>
<th>Ho, slope=0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sonora</td>
<td>2</td>
<td>-1.900E-05</td>
<td>-2.1</td>
<td>0.0505</td>
<td>Fail to reject</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>-1.788E-05</td>
<td>-2.58</td>
<td>0.0203</td>
<td>Reject</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>-3.200E-05</td>
<td>-3.15</td>
<td>0.0062</td>
<td>Reject</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>-2.035E-05</td>
<td>-2.42</td>
<td>0.0279</td>
<td>Reject</td>
</tr>
</tbody>
</table>

ETM+ Band 3 & AWiFS Band 3 (Sonora)
- ETM+: -5.866e-8x + 0.245
- AWiFS: -1.893e-5x + 0.242

ETM+ Band 4 & AWiFS Band 4 (Sonora)
- ETM+: 1.434e-8x + 0.377
- AWiFS: -3.193e-5x + 0.358

ETM+ Band 5 & AWiFS Band 5 (Sonora)
- ETM+: -1.11e-6x + 0.431
- AWiFS: -2.035e-5x + 0.458
Sensitivity Studies (Test Scenes)

- RVPN (P40R33)
- Sonora (P38R38)
- Range Land (P35R30)
- Grass Land (P31R31)
- Deciduous Forest (P14R31)
- Coniferous Forest (P46R30)
Spectral Differences Uncertainty

- SBAF were derived using hyperspectral EO-1 Hyperion measurements
- To understand the impact of the sensor spectral response differences on TOA reflectance measurements, the following equations were used

\[
SBAF = \frac{\int \rho_\lambda RSR_\lambda(ETM+) d\lambda}{\int \rho_\lambda RSR_\lambda(AWiFS) d\lambda} = \frac{\left(\int \rho_\lambda RSR_\lambda(ETM+) d\lambda\right)}{\left(\int RSR_\lambda(AWiFS) d\lambda\right)}
\]

\[
\rho^{*}_{ETM+} = \frac{\rho_{ETM+}}{SBAF}
\]
Spectral Differences Uncertainty

<table>
<thead>
<tr>
<th>Bands</th>
<th>Libya 4</th>
<th>Sonora</th>
<th>RVPN</th>
<th>Grassland</th>
<th>Rangeland</th>
<th>Deciduous</th>
<th>Coniferous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Path/Row</td>
<td>P181R40</td>
<td>P38R38</td>
<td>P40R33</td>
<td>P31R31</td>
<td>P35R30</td>
<td>P14/R31</td>
<td>P46/R30</td>
</tr>
</tbody>
</table>

(SBAF-1)x100 for the ETM+ and AWIFS

<table>
<thead>
<tr>
<th>Band</th>
<th>Libya 4</th>
<th>Sonora</th>
<th>RVPN</th>
<th>Grassland</th>
<th>Rangeland</th>
<th>Deciduous</th>
<th>Coniferous</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.50</td>
<td>1.58</td>
<td>0.41</td>
<td>0.36</td>
<td>0.22</td>
<td>-1.27</td>
<td>-1.62</td>
</tr>
<tr>
<td>3</td>
<td>1.45</td>
<td>1.02</td>
<td>0.86</td>
<td>1.27</td>
<td>0.53</td>
<td>-1.45</td>
<td>-2.62</td>
</tr>
<tr>
<td>4</td>
<td>0.26</td>
<td>-0.44</td>
<td>-0.67</td>
<td>0.97</td>
<td>-0.03</td>
<td>1.18</td>
<td>0.68</td>
</tr>
<tr>
<td>5</td>
<td>-2.87</td>
<td>-1.45</td>
<td>-1.86</td>
<td>-1.79</td>
<td>-0.91</td>
<td>-2.43</td>
<td>-3.54</td>
</tr>
</tbody>
</table>

- The simulated percent difference in TOA reflectance that is expected ONLY due the differences in spectral responses between the AWiFS and ETM+ sensors for different land cover types is typically within ~3%
Spatial Resolution Uncertainty

- To check the sensitivity of the ROIs due to differing spatial resolution, the 30 m TM data was resampled (cubic convolution) to 60 m, 100 m, 250 m, and 500 m spatial resolution.
- For spatial analysis, the ROI in original image was always chosen to be 50X50 pixels.
- Mean and Maximum APD were calculated for each band.

<table>
<thead>
<tr>
<th>Resolution</th>
<th>ROI Pixels</th>
<th>X-axis</th>
<th>RangeLand Band-1</th>
<th>Coniferous Band-7</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 m to 30 m</td>
<td>50 x 50</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 m to 60 m</td>
<td>25 x 25</td>
<td>2</td>
<td>0.002</td>
<td>0.008</td>
</tr>
<tr>
<td>30 m to 100 m</td>
<td>15 x 15</td>
<td>3.333</td>
<td>0.004</td>
<td>0.020</td>
</tr>
<tr>
<td>30 m to 250 m</td>
<td>6 x 6</td>
<td>8.333</td>
<td>0.012</td>
<td>0.053</td>
</tr>
<tr>
<td>30 m to 500 m</td>
<td>3 x 3</td>
<td>16.667</td>
<td>0.024</td>
<td>0.158</td>
</tr>
</tbody>
</table>

APD Vs spatial resolution

![APD vs spatial resolution graph](image-url)
Mis-registration Uncertainty

To check the sensitivity of the regions to image geometry, a moving window technique was used.

The selected ROI (100x100 pixels) were shifted by few pixels (1, 2, 3, 4, 5, 10, 15, 20, 25) in horizontally right/left and vertically up/down.

Absolute % difference (APD) for each ROI (r) and scene (s)

$$\text{APD}_{sr} = \left( \frac{\mu_{sr} - \mu_{sr'}}{\mu_{sr}} \right) \times 100$$

$$\text{APD}_s = \text{mean}(\text{APD}_{sr})$$

$$\text{APD} = \text{mean}(\text{APD}_s)$$

### GrassLand

- B and 1
  - $y = 0.0518x + 0.022$
  - $R^2 = 0.9993$

### Coniferous Forest

- Band 7
  - $y = 0.2438x + 0.0929$
  - $R^2 = 0.9992$
Image-to-Image (I2I) Assessment (Sonoran & Railroad Valley Test Sites)

- The I2I characterization was performed to compare the accuracy of AWiFS against the GLS2000 dataset as a reference image.
  - A total of 33 AWiFS images over Railroad Valley, and 22 images over Sonoran were used.
  - The AWiFS images were typically registered to within one pixel to the GLS2000 dataset.

Vector scale: 1:2800

252_045_D_20090420

248_040_D_20081014
The MS bands are registered to sub-pixel accuracy.

The results show that alignment between bands 2, 3 and 4 is very good, while the alignment errors with band 5 are higher.
NLCD Tree Canopy Change Assessment

Seattle (Mostly Forest)

Data

Tree Canopy

Tree Canopy Change

Change comparison for Tree Canopy derived from Landsat and AWiFS Images

<table>
<thead>
<tr>
<th>Change Agreement</th>
<th>Decrease area</th>
<th>Increase area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seattle</td>
<td>87.40%</td>
<td>84%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bands</th>
<th>TM 2000-09-25</th>
<th>Bands 7, 4, 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NLCD 2001 (30 m)</td>
<td></td>
</tr>
<tr>
<td>Bands</td>
<td>TM 2006-09-02</td>
<td>Bands 7, 4, 3</td>
</tr>
<tr>
<td></td>
<td>2006 TM (30 m)</td>
<td></td>
</tr>
<tr>
<td>Bands</td>
<td>AWiFS 2006-09-01</td>
<td>Bands 5, 4, 3</td>
</tr>
<tr>
<td></td>
<td>2006 AWiFS (56 m)</td>
<td></td>
</tr>
</tbody>
</table>
Arizona Warm Fire (July 06, 2006)  
Mostly Ponderosa pine with a Pinyon Juniper/ Shrub mixture at lower elevations on the east

Pre AWiFS: June 5, 2006  
Post AWiFS: June 4, 2007  
Pre L5 TM: May 30, 2006  
Post L5 TM: June 18, 2007

Visually the maps look similar

In the TM B5 map, the confusion between the unburned and low severity class outside the perimeter is because of using B5 which is not as sensitive as B7

In the AWiFS map, the confusion is reduced because of the coarser spatial resolution of 56 m that may cause a smoothing effect

Table shows a comparison of “official TM” versus “AWiFS” dNBR

<table>
<thead>
<tr>
<th>Class Severity</th>
<th>Pixel Counts</th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
<th>Class 4</th>
<th>Total</th>
<th>% agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unburned to low</td>
<td></td>
<td>9713</td>
<td>4301</td>
<td>59</td>
<td>1</td>
<td>14223</td>
<td>68.3</td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td>4224</td>
<td>17114</td>
<td>3098</td>
<td>40</td>
<td>24479</td>
<td>69.9</td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td>14</td>
<td>3318</td>
<td>15478</td>
<td>2781</td>
<td>21591</td>
<td>71.7</td>
</tr>
<tr>
<td>High</td>
<td></td>
<td>0</td>
<td>16</td>
<td>2815</td>
<td>11535</td>
<td>14366</td>
<td>79.6</td>
</tr>
</tbody>
</table>
Science Utility Evaluation Summary

- Indicates that AWiFS data is potentially a usable alternative to Landsat during the mission gap
  - The higher radiometric resolution (10 bits), larger swath area coverage (740 km), and a frequent repeat cycle (five days) will be an advantage for science applications, allowing for the increased likelihood of cloud-free acquisitions and reduction in the processing and handling of a lower number of images
  - The lack of an AWiFS equivalent to the Landsat spectral Bands 1 & 7 can have an adverse impact on a few assessments, likely resulting in reduced but acceptable derived-product accuracy and sensitivity
  - The coarser spatial resolution of AWiFS could negatively impact the ability to discriminate fine-scale landscape features, especially those related to urban development (It is possible, however, that the disadvantage of lower spatial resolution could be offset by the more frequent repeat coverage of AWiFS)
  - Lack of thermal band will have an obvious negative impact on applications depending on the use of thermal (e.g. Water management)
Future Work

• Investigate differences between AWiFS quad AC/BD
• Get additional data to track the long term stability of the AWiFS sensor
• Characterize the uncertainties due to spectral mismatches, spatial, radiometric, BRDF, and atmospheric impacts
• Quantify the science utility and investigate the impact of cross-cal coefficients on LCLUC applications
• Finalize the AWiFS evaluation from the CEOS Tuz Golu and Dome-C campaigns
• ResoureSat-2 characterization
Contributors

- The slides in this presentation include contributions from a number of individuals in various organizations
  - USDA/FAS (Tetrault)
  - SDSU (Helder, Shrestha, Mishra)
  - USGS/EROS (Stensaas, Howard, McKinley, Homer, Yang, Xian, Vogelmann, Chen, Tolk, Sampath)
  - NASA/MCST (Xiong, Angal, Choi)
  - Others!

- This work was supported by Dr. Gutman through the NASA LCLUC Grant NNH08AI30I
Catalog of Worldwide Test Sites for Sensor Characterization

http://calval.cr.usgs.gov/sites_catalog_map.php

Gyanesh Chander, CEO Tech QA-06-01, 2/06
SST Inc., contractor to the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD. Work performed under USGS contract 08HQG062F.

Scope of Test Sites
- Test sites are central to any future Quality Assurance/Quality Control (QA/QC) strategy.
- Test sites provide a convenient means of obtaining information to verify sensor performance.
- Test sites are the only practical means of deriving knowledge of these issues between sensors.
- Test sites allow, at some level, means of bridging anticipated data gaps caused by lack of measurement variability, due to lack of co-located in-flight sensors.

Characteristics of Sensors which can Benefit from Test Sites
- Cross-calibration
- Stability
- Modulation Transfer Function (MTF)
- Uniformity
- Image quality
- Polarization
- Spectral
- Signal-to-Noise Ratio (SNR)
- Geolocation
- Camera model
- Band-to-band
- Internal Geometry

Well-Established Site Selection Criteria for Radiometry Test Sites
- High spatial uniformity over a large area (within ±5%)
- Surface reflectance [0, 1] greater than 0.5
- Flat spectral reflectance
- Temporally consistent surface properties (within ±5%)
- Horizontal surface with nearly Lambertian reflectance
- At high altitude, far from oceans, urban, and industrial areas
- In solid regions with low probability of cloud cover

CEOS Reference Standard Test Sites
- The instrumented sites are primarily used for field campaigns to obtain radiometric gain. These sites can serve as a focus for international efforts, facilitating traceability and cross-comparison to evaluate efficacies of different sensors in a harmonized manner.
- The pseudo-instrument desert sites have high reflectance with low aerosol loading and practically no vegetation; Consequently, these sites can be used to evaluate the long-time stability of a sensor and facilitate cross-comparison of multiple sensors.

Online Test Site Catalog

Summary
- The test site catalog provides a comprehensive list of prime candidate test sites for consideration as benchmark sites for the pre-launch qualification of space-based optical sensors.
- The online test site catalog provides easy public high site access to this vital information for the global community.
- The incompleteness of available information on even these prime test sites is an indication that more coordination and documentation are still needed to facilitate the wider use of calibration test sites in remote sensing.

Proposed Future Plans
- Gather complete site characterization data & define core measurements (eg. instruments)
- Create an operational network of land sites (“Landnet”) & develop online data access infrastructure
- Encourage agencies to acquire, archive, and provide data over the CEOS sites
- Integrate the catalog into the CEOS CalVal portal
- Establish traceability chain for primary test data
- Develop “best practice” guidance on site characterization and its use
COVE (CEOS Visualization Environment)

CEOS Committee on Earth Observation Satellites

TEAM:
SEO Sponsor:
Brian D. Killough, Ph.D.
CEOS Systems Engineering Office (SEO)
Email: Brian_D.Killough@nasa.gov
Phone: 757-864-7047

SEO Team Members:
Shelley K. Stover
Science Systems & Applications Inc.
Email: Shelley.K.Stover@nasa.gov
Phone: 757-593-4962

WGCV Customer:
Gyanesh Chander
SGF, Inc., Contractor to the USGS EROS
Email: gchander@usgs.gov
Phone: 605-594-2554

AMA, Inc., Developer:
Sanjay Gawda, Ph.D.
AMA, Inc.
Email: gawda@ama-inc.com
Phone: 757-865-9046

OVERVIEW:
The CEOS Visualization Environment (COVE) tool is a browser-based system that allows users to display satellite sensor coverage areas and for the identification of coincident scene locations. The NASA CEOS Systems Engineering Office (SEO) worked with the Committee on Earth Observing Satellites (CEOS) Working Group on Calibration and Validation to develop the COVE tool.

COVE is currently operating and planning hundreds of Earth observation satellites, and it can be used to identify corresponding image pairs in near-real-time. It supports bookmarking of particular views and datasets that can be easily reloaded in the future.

FEATURES:
Key features and capabilities include:
- User-defined evaluation periods (start and end dates)
- Regions of interest (rectangular areas)
- Predefined geographical locations or a point search (specific latitude/longitude)

FUTURE WORK:
COVE is being developed on a flexible framework that allows it to remain easily extendable. Future work under consideration includes:
- Output: data validation and verification testing
- Planning for specific WGCV campaigns
- Earth maps
- Synchronization of work environment
- Additional missions
- Civil/Val ground test site selection

MISSIONS & INSTRUMENTS
COVE currently includes the following missions and instruments:
- Mission: LANDSAT-7
- Instruments: ETM+
- Mission: CERES
- Instruments: MERIS
- Mission: Envisat
- Instruments: MERIS
- Mission: GOSAT
- Instruments: TAM-OCTS
- Mission: IRS-P6
- Instrument: IRS-H

and more to come!

IMAGE A: Orbital parameters are added to a database from which COVE processes the data and displays the results to the user.

IMAGE B: The COVE User Interface is divided into 4 sections: Dynamic search results, COVE familiarization, maps, and a Q&A information panel, and Google Earth Viewport.

IMAGE C: Multiple views display different views of the Earth at once, and it can also be synced to a single viewport for easy navigation.

IMAGE D: Brightly colored lines represent satellite sensor viewing areas. Overlapping scenes can be easily identified.

IMAGE E: Areas of interest can be specified as a single point or as a region bounded by multiple points. All return data over the area are identified.

IMAGE F: Confidence calculations for multiple missions. The numbers displayed in red indicate the level of confidence in the data. Detailed results are displayed on the surface of the Earth and can be exported as CSV or KML files.
Future ResourceSat Sensors

● ResourceSat-2
  – Launch currently scheduled for Q3 2010
  – Virtually identical to Resourcesat-1 (with miniaturization)
  – Improved solar array and power handling system
  – Radiometric resolution of LISS-III/IV will be improved from 7 bits to 10 bits
  – AWiFS will have improved multi-linear gains
  – OBSSR will be increased in size (2 each at 200 GB)
  – Resourcesat-2 has a 7-10 year design life

● ResourceSat-3
  – Increased resolution and more spectral bands to existing sensors
  – AWiFS (A & B) improved to 25 m resolution, 600 km swath
  – LISS-III will remain at 23.5 m resolution with 2 additional bands
  – Thermal at 70 m resolution under consideration
  – LISS-IV will remain at 5.8 m resolution, but swath will be increased
  – Possible addition of new sensors with 25 km swath:
    ● LISS-V (PAN) at 2.5 m resolution
    ● Hyperspectral at 25 m resolution (~200 Bands)
Backup Slides
IRS-P6 Data Through INPE

- Since 09/15/2009, INPE is receiving and processing ResourceSat-1 imagery
  - LISS-3 (23 m) and AWiFS (56 m)
  - LISS-4 (5 m) is not included

- The images cover South America region in the range of INPE’s reception antenna in Cuiaba, MT

- Images are costless distributed in the catalog http://www.dgi.inpe.br/CDSR/
### AWiFS Product Options (GeoEye)

<table>
<thead>
<tr>
<th>Standard Products</th>
<th>Value Added Products</th>
<th>Level</th>
<th>Type of Correction Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Path/Row Based</td>
<td>Ortho Products</td>
<td>Level 0</td>
<td>No correction (not available for sale)</td>
</tr>
<tr>
<td>2 Shift Along Track</td>
<td></td>
<td>Level 1</td>
<td>Radiometric Correction only</td>
</tr>
<tr>
<td>3 Quadrant Products</td>
<td></td>
<td>Level 2 (Standard)</td>
<td>Radiometric and Geometric Correction</td>
</tr>
<tr>
<td>4 Georeferenced Products</td>
<td></td>
<td>Level 3</td>
<td>Precision Correction (using GCPs)</td>
</tr>
</tbody>
</table>

#### Resampling Options | Map Projections | Earth Ellipsoids | Data Formats |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cubic Convolution</td>
<td>Polyconic</td>
<td>Clark 1866</td>
<td>LGSOWG Superstructure Format</td>
</tr>
<tr>
<td>Nearest Neighbor</td>
<td>Lambert Conformal Conical</td>
<td>Int’l 1909</td>
<td>Fast Format</td>
</tr>
<tr>
<td>Bilinear</td>
<td>Universal Transverse Mercator</td>
<td>GRS 1980</td>
<td>GeoTIFF (Gray Scale)</td>
</tr>
<tr>
<td>16 Point Sinc</td>
<td>Space Oblique Mercator</td>
<td>Everest</td>
<td>GeoTIFF (RGB)</td>
</tr>
<tr>
<td>Kaiser -16</td>
<td>Space Oblique Mercator</td>
<td>WGS 84</td>
<td>HDF</td>
</tr>
<tr>
<td>4 Point Sinc</td>
<td>Space Oblique Mercator</td>
<td>Bessel</td>
<td></td>
</tr>
</tbody>
</table>

- Space Imaging (now GeoEye) was granted a license to receive & distribute AWiFS imagery from their ground station in Oklahoma (Jan. 2005)
- Effective 1 January 2009, EOTec became the exclusive distributors for Resourcesat Data in North America (GeoEye is key partner)
USDA Satellite Imagery Archive

The USDA AWiFS imagery product was standardized using the following parameters

1. Item: AWiFS orthorectified quad. L1T (terrain-corrected)
2. Identification: path, row, quad, date
3. Projection: Lambert Conformal Conic
4. Resampling: Cubic convolution
5. Datum: WGS84
6. Orientation: North up
7. Format: 4-bands, unstacked geoTIFF
8. Bit depth: 8-bits (10 bits for data processed after 4/1/2008)
9. Media: CDROM
10. License for redistribution: Tier 2 (Federal/Civilian agencies)
AWiFS Data Holding in USDA

- 2004 to 2010 data available in the USDA Archive Explorer v.3.1 (6,314 AWiFS scenes)
- 2004 to 2007 data available in EE (2,922 scenes)
Conversion to TOA Reflectance

- When comparing images from different sensors, there are three advantages to using TOA reflectance instead of at-sensor spectral radiance:
  - First, it removes the cosine effect of different solar zenith angles due to the time difference between data acquisitions.
  - Second, TOA reflectance compensates for different values of the exoatmospheric solar irradiance arising from spectral band differences.
  - Third, the TOA reflectance corrects for the variation in the Earth-Sun distance between different data acquisition dates. These variations can be significant geographically and temporally.
The Figure of Merit ("alpha") is defined as the intersecting areas of two spectral response functions divided by the union of the two areas:
- $\alpha = 1.0$ indicates complete spectral agreement between two bands
- $\alpha = 0.0$ indicates complete disagreement

\[ \alpha = \frac{A \cap B}{A \cup B} \]

where $A$ & $B$ represent the areas under the RSR curves.

The figure of merit approach is plagued by the lack of spectral scene content information, but at least provides a non-unity factor:
- For a spectrally flat scene, the RSR differences will not matter

The figure of merit can be viewed more as a quantization of ‘potential’ differences in cross-cal between the sensors.

### Figure of Merit (alpha)

<table>
<thead>
<tr>
<th>Bands</th>
<th>ETM+</th>
<th>TM</th>
<th>MODIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.806</td>
<td>0.671</td>
<td>0.302</td>
</tr>
<tr>
<td>3</td>
<td>0.746</td>
<td>0.719</td>
<td>0.692</td>
</tr>
<tr>
<td>4</td>
<td>0.686</td>
<td>0.706</td>
<td>0.304</td>
</tr>
<tr>
<td>5</td>
<td>0.694</td>
<td>0.551</td>
<td>0.211</td>
</tr>
</tbody>
</table>
Geometric Assessment

- Completed using the Image Assessment System (IAS) which was developed for Radiometric and Geometric Characterization and Calibration for the Landsat Program

- **Image to Image (I2I) registration assessment tool**
  - I2I is usually performed to compare the registration between two images
  - One image is selected as reference and another as the search image
  - Image chips are selected from reference image and are correlated with search image
  - The co-registration results provide an insight to the relative accuracy of the search image with respect to the reference image
  - When the correlated points are plotted in the image, it also helps to detect any systematic bias in the image

- **Band to Band (B2B) registration assessment tool**
  - B2B is performed to ensure that the proper band alignment parameters are provided
  - It is typically done by registering each band against every other band
Image-to-Image (I2I) Assessment (Sonoran & Railroad Valley Test Sites)

### Mean error & RMSE (Sonoran Site)

<table>
<thead>
<tr>
<th></th>
<th>Pixels</th>
<th>Meters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Line</td>
<td>Sample</td>
</tr>
<tr>
<td>Sonoran</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.48</td>
<td>0.18</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.34</td>
<td>0.38</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.60</td>
<td>0.56</td>
</tr>
</tbody>
</table>

### Mean error & RMSE (Railroad Valley Site)

<table>
<thead>
<tr>
<th></th>
<th>Pixels</th>
<th>Meters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Line</td>
<td>Sample</td>
</tr>
<tr>
<td>RVPN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.36</td>
<td>0.30</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.15</td>
<td>0.22</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.41</td>
<td>0.40</td>
</tr>
</tbody>
</table>
The circular error plot, with the red circle showing CE90 and the blue circle showing CE95
Linear equations are fitted to the long-term TOA reflectance trends
- Slope values are very small: prove the long term stability of sensors
- There are constant offsets: caused by a combination of the spectral signature of the ground target, atmospheric composition and the RSR characteristics

The annual oscillation were caused by BRDF effect
NLCD Tree Canopy Change Assessment

San Diego (Forest, Grassland, Shrubland, etc.)

Decrease in tree canopy estimate is relatively easy to detect (spectral variation due to fire disturbance, clear-cut)

Increase is a gradual change. Increase in tree canopy estimate is harder to detect. (Spectral mixing makes it harder to detect re-growth)

Change comparison for Tree Canopy derived from Landsat and AWiFS Images

| Change Agreement |
|------------------|------------------|
| San Diego        |                  |
| Decrease area    | Increase area    |
| 56 m             | 82.10%           |
|                  | 42%              |
Monitoring Trends in Burn Severity: MTBS

- Mapping the Location, Extent and Severity of Fires in the United States
- Burn severity products are based on the differenced Normalized Burn Ratio (dNBR) derived from Landsat TM & ETM+ data:
  - Normalize Burn Ratio (NBR) = \( \frac{B4 - B7}{B4 + B7} \)
  - dNBR = PreFire NBR – PostFire NBR
- Burn Severity is visually estimated from the dNBR
MTBS Burn Severity Maps Assessment
Data Sources

Pacific NW Columbia Complex Fire
(Aug 21, 2006)
Primarily evergreen forest but also in surrounding agricultural lands and adjacent to a previous burn

Arizona Warm Fire
(July 06, 2006)
Mostly Ponderosa pine with a Pinyon Juniper/Shrub mixture at lower elevations on the east

Pre AWiFS June 26, 2006
Post AWiFS June 26, 2007
Pre AWiFS June 5, 2006
Post AWiFS June 4, 2007
Pre L5 TM June 25, 2006
Post L5 TM June 12, 2007
Pre L5 TM May 30, 2006
Post L5 TM June 18, 2007
### MTBS dNBR Burn Severity Maps:
Pacific NW Columbia Fire [Aug 21, 2006]

#### Pixel Counts

<table>
<thead>
<tr>
<th>Class Severity</th>
<th>Pixel Counts</th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
<th>Class 4</th>
<th>Total</th>
<th>% agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unburned to low</td>
<td>Class 1</td>
<td>62997</td>
<td>12866</td>
<td>4102</td>
<td>802</td>
<td>81933</td>
<td>76.9</td>
</tr>
<tr>
<td>Low</td>
<td>Class 2</td>
<td>13733</td>
<td>9795</td>
<td>5837</td>
<td>958</td>
<td>30472</td>
<td>32.14</td>
</tr>
<tr>
<td>Moderate</td>
<td>Class 3</td>
<td>3919</td>
<td>6437</td>
<td>9287</td>
<td>3598</td>
<td>23277</td>
<td>39.9</td>
</tr>
<tr>
<td>High</td>
<td>Class 4</td>
<td>293</td>
<td>1046</td>
<td>4093</td>
<td>10299</td>
<td>15733</td>
<td>65.46</td>
</tr>
</tbody>
</table>
### NLCD Wetland Mapping and Monitoring

**Comparison of Modeled Sub-Pixel Percent of Water**

<table>
<thead>
<tr>
<th>Input Imagery</th>
<th># of training samples</th>
<th># of test samples</th>
<th>Ave Error (%)</th>
<th>Relative Error (%)</th>
<th>Correlation Coeff. R</th>
</tr>
</thead>
<tbody>
<tr>
<td>TM Image</td>
<td>5000</td>
<td>500</td>
<td>6.4</td>
<td>0.15</td>
<td>0.96</td>
</tr>
<tr>
<td>AWiFS Image</td>
<td>5000</td>
<td>500</td>
<td>9.8</td>
<td>0.23</td>
<td>0.90</td>
</tr>
</tbody>
</table>
Survey of Well-Established Site Selection Criteria for Radiometry Test Sites

- High spatial uniformity over a large area (within 3%)
  - Minimize misregistration and adjacency effects
- Surface reflectance [0, 1] greater than 0.3
  - To provide higher SNR and reduce uncertainty due to atmosphere
- Flat spectral reflectance spectrum
  - Reduce uncertainties due to different RSR
- Temporally invariant surface properties (within 2%)
  - To reduce BRDF, spectral, surface reflectance effects
- Horizontal surface with nearly lambertian reflectance
  - Minimize uncertainty due to different solar illumination & observation geometry
- At high altitude, far from ocean, urban, and industrial areas
  - Minimize aerosol loading and atmospheric water vapor
- In arid regions with low probability of cloud cover
  - Minimize precipitation that could change soil moisture
ResourceSat-1 (IRS-P6) Overview

- The IRS-P6 satellite was launched into a polar sun-synchronous orbit on Oct. 17, 2003, with a design life of 5 years
- IRS-P6 carries three sensors
  - High Resolution Linear Imaging Self-Scanner (LISS-IV)
  - Medium Resolution Linear Imaging Self-Scanner (LISS-III)
  - Advanced Wide Field Sensor (AWiFS)

<table>
<thead>
<tr>
<th>IRS-P6 Orbit and Coverage Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit Altitude</td>
</tr>
<tr>
<td>Orbit Inclination</td>
</tr>
<tr>
<td>Orbit period</td>
</tr>
<tr>
<td>Number of Orbits per day</td>
</tr>
<tr>
<td>Equatorial crossing time</td>
</tr>
<tr>
<td>Repeat Cycle (LISS-III)</td>
</tr>
<tr>
<td>Repeat Cycle (LISS-IV)</td>
</tr>
<tr>
<td>Distance between adjacent paths</td>
</tr>
<tr>
<td>Distance between successive ground tracks</td>
</tr>
<tr>
<td>Lift-off Mass</td>
</tr>
<tr>
<td>Ground trace velocity</td>
</tr>
<tr>
<td>Orbits/cycle</td>
</tr>
<tr>
<td>Semimajor axis</td>
</tr>
<tr>
<td>Eccentricity</td>
</tr>
<tr>
<td>Mission Life</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IRS-P6 Sensor Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution (m)</td>
</tr>
<tr>
<td>Swath (km)</td>
</tr>
<tr>
<td>Spectral Bands (μm)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Quantization (bits)</td>
</tr>
<tr>
<td>Integration Time (msec)</td>
</tr>
<tr>
<td>No. of gains</td>
</tr>
<tr>
<td>Sensor</td>
</tr>
<tr>
<td>CCD Arrays</td>
</tr>
<tr>
<td>CCD Size (μm)</td>
</tr>
<tr>
<td>Focal Length (mm)</td>
</tr>
<tr>
<td>Cross-track FOV for pixel (radiance)</td>
</tr>
<tr>
<td>Power (W)</td>
</tr>
<tr>
<td>Weight (kg)</td>
</tr>
<tr>
<td>Data Rate (MBPS)</td>
</tr>
</tbody>
</table>
## RESOURCESAT-1 PRICING

<table>
<thead>
<tr>
<th>Product Suite</th>
<th>Resolution</th>
<th>Band</th>
<th>Scene Size</th>
<th>Unit Price</th>
<th>$50K-$100K (5%)</th>
<th>$101K-$250K (9%)</th>
<th>&gt; $250K (19%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georectified - Path Oriented</td>
<td>5m</td>
<td>B&amp;W</td>
<td>70 x 70 km</td>
<td>$2,500</td>
<td>$2,375</td>
<td>$2,000</td>
<td>$2,250</td>
</tr>
<tr>
<td></td>
<td>5m</td>
<td>Multispectral</td>
<td>23 x 23 km</td>
<td>Quote</td>
<td>Quote</td>
<td>Quote</td>
<td>Quote</td>
</tr>
<tr>
<td></td>
<td>23m</td>
<td>Multispectral</td>
<td>141 x 141 km</td>
<td>$2,500</td>
<td>$2,375</td>
<td>$2,300</td>
<td>$2,250</td>
</tr>
<tr>
<td></td>
<td>56m</td>
<td>Multispectral</td>
<td>350 x 350 km</td>
<td>$700</td>
<td>$700</td>
<td>$700</td>
<td>$700</td>
</tr>
<tr>
<td>Georectified - Map Oriented</td>
<td>5m</td>
<td>B&amp;W</td>
<td>70 x 70 km</td>
<td>$2,750</td>
<td>$2,613</td>
<td>$2,530</td>
<td>$2,475</td>
</tr>
<tr>
<td></td>
<td>5m</td>
<td>Multispectral</td>
<td>23 x 23 km</td>
<td>Quote</td>
<td>Quote</td>
<td>Quote</td>
<td>Quote</td>
</tr>
<tr>
<td></td>
<td>23m</td>
<td>Multispectral</td>
<td>141 x 141 km</td>
<td>$2,750</td>
<td>$2,613</td>
<td>$2,530</td>
<td>$2,475</td>
</tr>
<tr>
<td></td>
<td>56m</td>
<td>Multispectral</td>
<td>350 x 350 km</td>
<td>$850</td>
<td>$808</td>
<td>$782</td>
<td>$750</td>
</tr>
<tr>
<td>Orthorectified</td>
<td>5m</td>
<td>B&amp;W</td>
<td>70 x 70 km</td>
<td>$3,575</td>
<td>$3,396</td>
<td>$3,260</td>
<td>$3,218</td>
</tr>
<tr>
<td></td>
<td>5m</td>
<td>Multispectral</td>
<td>23 x 23 km</td>
<td>Quote</td>
<td>Quote</td>
<td>Quote</td>
<td>Quote</td>
</tr>
<tr>
<td></td>
<td>23m</td>
<td>Multispectral</td>
<td>141 x 141 km</td>
<td>$3,575</td>
<td>$3,396</td>
<td>$3,260</td>
<td>$3,218</td>
</tr>
<tr>
<td></td>
<td>56m</td>
<td>Multispectral</td>
<td>350 x 350 km</td>
<td>$1,100</td>
<td>$1,045</td>
<td>$1,012</td>
<td>$950</td>
</tr>
</tbody>
</table>

**NOTES:**
- 5m Multispectral orders must go through Collection Feasibility and Custom Quote Process prior to order acceptance.
- Large Area Discount threshold calculations are based on Unit Price.
- Large Area Discounts apply to each order and are not cumulative.
- Large Area Discount does not apply to Path Oriented 56m Multispectral 350 x 350 km scenes.

---

Earth Observation Technologies, LLC  
2120 LeRoy Place NW  
Washington, DC 20008  
TEL/FAX: 1-202-232-3138  
Email for Orders/Inquiries: info@eotec.com  
Imagery Search: http://imagesearch.geoeye.com/
AWiFS Ortho Production

- Ancillary Data Compilation (CONUS)
  - DEM: 1-arcsecond NED
    - SRTM-3 used for scenes straddling US borders
  - Imagery: USGS DOQs
    - Reduced resolution DOQs used for AWiFS control (32 m GSD) ~12 m CE90 positional accuracy (1:24K)

- Ancillary Data Compilation (International)
  - DEM: SRTM-3
    - Alaska NED and Canada CDED used in high latitudes
  - Imagery: GeoCover2000 Landsat orthos
    - ~110 m CE90 positional accuracy
    - Reference image accuracy is limiting factor for international ortho products
NLCD Wetland Mapping and Monitoring
Data Sources

- **Challenges**
  - Composition of wetlands is complex and often with mixed components (vegetation species, soil, water, etc.)
  - Condition of wetlands are dynamic (seasonal, interannual)
  - Spatial distribution of wetlands are complex

- **Remote Sensing Data**
  - QuickBird: Sept 29, 2006
  - Landsat TM: Sept 26, 2006
  - IRS-P6 AWiFS: Sept 27, 2006

- **Field data** (Wetland type, vegetation, fraction of water, land/soil, etc.)